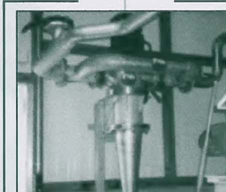
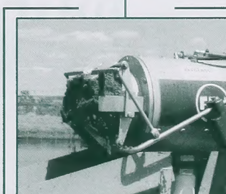
SOLID-LIQUID SEPARATION OF LIVESTOCK MANURE





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Introduction

Solid-liquid separation is a manure treatment technology that separates a portion of the solids from liquid manures. Physical solid-liquid separation processes rely on the density, size, or shape of the individual particles. Effective solid-liquid separation can remove a substantial amount of the organic solids from fresh liquid (slurry) manure and offers the benefits of producing nutrient rich solids.

Advantages:

a) *Phosphorus (P) reduction in liquid fraction* - Much of the P in the manure (96%) is in the solid fraction, so that P compounds are largely removed in solid fraction. Nitrogen (N) and P contents in the separated solids may be as high as 2 and 5%, respectively, depending on manure characteristics and type of equipment. The addition of chemicals into manure before separation can significantly enhance the P content in the separated solids.

b) *Ease of handling and transport* - The effluent (liquid portion) from a solid-liquid separator has a lower potential to plug transfer pipes due to the reduced solids. Also, less power is required to pump the same volume of material because the percentage of solids in the liquid manure is decreased. Solid-liquid separation can make it easier to use irrigation systems to pump manure long distances. It reduces the pressures at the pump minimizing the risk of ruptured seals which can lead to manure spills.

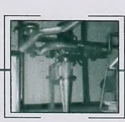
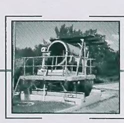
c) *Odour reduction in liquid-fraction of manure slurry* - Odour generation largely depends on the amount of odour-producing organic substances remaining in the liquid. The organic loading of the separated liquid fraction in treatment lagoons tends to be reduced following solid-liquid separation. The solid-fraction of the slurry becomes more concentrated with organic material.

d) *Lagoon volume reduction* - Separating manure solids from slurry before putting it into a lagoon reduces total slurry storage volume by 6 to 10 percent and volatile solids loading by 30 to 50 percent.

e) *Nutrient reduction in slurries* - Removing solids that retain their nutrients can help reduce nutrient loading on nearby field. The separated liquid has a lower potential to pollute surface water and groundwater. It contains less N, P, and other constituents. The separated liquid fraction can be treated and used as a recycled water source or stored and effectively applied to land.

Disadvantages:

a) *High cost* - Along with the capital cost expense of the separating device, some mechanical separation systems have high operating costs. Furthermore, two separate manure handling systems are needed, one to handle the liquid fraction and the other for the solids stream.


b) *Increased management requirements* - An operator must be knowledgeable to ensure the system is functioning properly. Regular maintenance is required to avoid breakdowns, depending on the type of separator. Increased concentration of phosphorus in solid phase must be managed properly.

Separation Techniques and Equipment

Several methods to separate solids from liquids are:

- Sedimentation: This technique uses gravity to settle solids out of the slurry.
- Mechanical separation: This technique utilizes gravitational means to separate the solids and liquids.
- Evaporation ponds: These may be effective in arid regions where much more water is removed by evaporation than is added by precipitation.
- Dehydration: This method uses heat to remove moisture and is unpopular because of the high initial cost, maintenance and energy requirements.
- Coagulation and Flocculation: this relatively new technique for solid-liquid separation uses chemicals to aggregate suspended solids (coagulation) to form settleable particles and to convert particles into large, rapidly settling flocs (flocculation).

Sedimentation

Settling basins are structures designed to separate solids from liquid manure by sedimentation. The inflow of manure into the settling basin is restricted to allow some of the solids to settle out before entering the settling basin. The liquids and some solids gradually drain into a holding pond, a treatment lagoon or to some other storage structure. Solids remaining in the basin are left to dry and then are removed. Settling basins should be shallow (typically 1 to 3 feet deep), long, wide and free draining. Flow velocity at the design flow rate should be less than 1 foot per second; a hydraulic retention time (average retention time for liquid manure flowing through the basin) of 20 to 30 minutes is desired.

Mechanical separators

The types of mechanical separators include screen separators, centrifuges, hydro-cyclones and presses (screw or belt type).

Screen separators

Screen separators include stationary inclined, vibrating, rotating, and in-channel flighted conveyor screens. All separators of this type involve a screen of a specified pore size that allows only solid particles smaller in size than the openings to pass through. This type of separator generally works best with manure which has a solids content of less than 5 percent (Bicudo, 2001).

Stationary inclined screen:

Stationary inclined screen separators use gravity to separate liquid manure from solids (Figure 1). Liquid manure is pumped to the top edge of the inclined screen. Liquids pass through the screen while the solids accumulate on the screen. The solids eventually move downward due to gravity and fluid pressure and are deposited on a collection pad or in an




auger. Apart from the pump used to move the liquid manure to the top of the screen, this system has no moving parts or power requirements. This type of screen separator is widely used to remove fibrous, coarse particles from dairy manure.

The drawback of the stationary inclined screen separator is that a biological slime builds up and clogs the openings. A separate wash-down system is required to keep the screen from clogging. Frequent brushing may be necessary to ensure that the holes remain unplugged (Fleming, 1986).

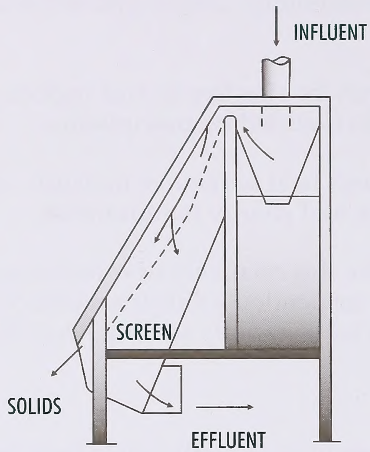


Figure 1. Stationary Inclined Screen adapted from Shutt et al., 1975

In-channel flighted conveyor screen:
This screen separator system consists of an inclined screen and a series of horizontal bars called flighted conveyors (Figure 2). The separator can be placed directly in an open manure channel which eliminates the need for a sump or a pit and a lift pump. A chain drags the flighted conveyors carrying liquid manure over the top of the inclined screen. Liquid passes through the screen and drains into the channel on the downstream side of the separator while the separated solids are deposited on a collection pad. The separating process is similar to that of the stationary inclined screen separator but the in-channel flighted conveyor screen separator requires more mechanical maintenance because moving parts are exposed to corrosive and abrasive material.

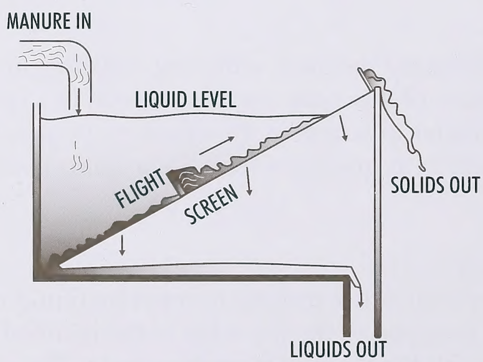
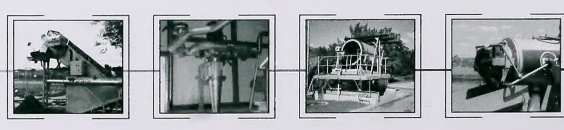


Figure 2. In-channel flighted conveyor screen adapted from Fleming, 1986



Rotating screen separator:
The rotating screen separator uses a continuously turning or rotating screen similar to a clothes dryer. Liquid manure passes through the separator at a controlled rate (Figure 3). A scraper removes the solids that collect on the screen while the liquid passing through the screen is collected in a tank.

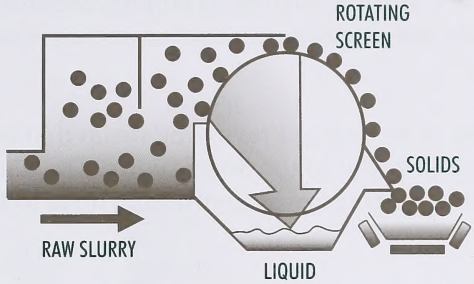


Figure 3. Rotating Screen adapted from Bicudo, 2001

Vibrating Screen
Liquid manure is pumped at a controlled rate onto the flat vibrating screen (Figure 4). The liquid flushes through the screen while the short, rapid reciprocating motion moves the solids to the screen edge where they are collected. The vibration reduces clogging of the screen. The power requirement is higher with this system than for the stationary inclined screen.

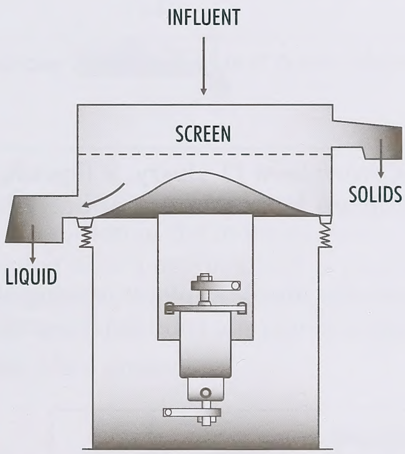
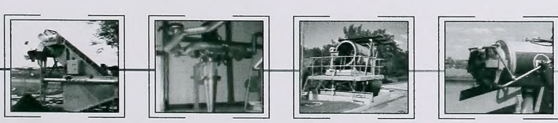


Figure 4. Vibrating Screen adapted from Shutt et al., 1975

Centrifugation
Centrifugation involves solid-liquid separation using centrifugal forces to increase the settling velocity of suspended particles using either centrifuges or hydrocyclones. These separators function best with liquid slurries of 5 to 8 percent solids and are not as efficient when the solids content is lower (Sheffield, 2000).



Centrifuge

Typically, centrifuges consist of a horizontal or vertical cylinder which continuously rotates at high velocities. Centrifugal forces separate the liquid and solids onto the inside wall of the cylinder into two layers. Centrifuges are very effective at solids separation and can achieve relatively low moisture levels. The initial cost is high, however, and the energy requirement is also quite high in comparison to other systems (Fleming, 1986). The two types of centrifuge separators are centrisieves and decanters.

Centrisieves:

Centrisieves (Figure 5) consist of an inclined revolving drum that is lined with a filter cloth. The slurry to be separated is pumped into the drum centre. The liquid leaves the drum through the filter cloth and the solids move by centrifugal force to the edge of the drum where they are removed separately.

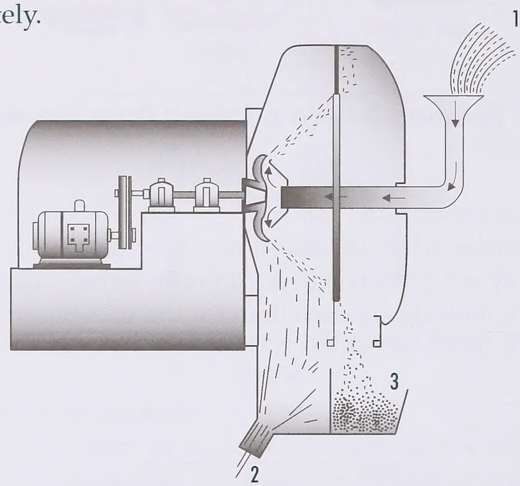


Figure 5. Centrisieve (1 slurry, 2 liquids, 3 solids) adapted from Glerum et al., 1975

Decanter Centrifuge:

In the case of decanter centrifuges (Figure 6), an auger turning at a slightly higher speed than the cylinder in which it is contained moves the solids to the conical part of the vessel where they are discharged.

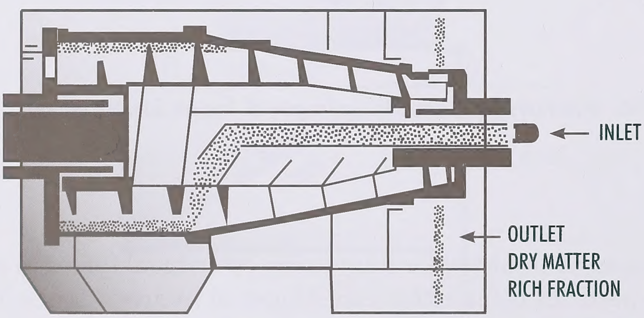


Figure 6. Decanting Centrifuge adapted from Møller et al., 2000

Hydrocyclones

Hydrocyclones are cone-shaped separators that have no moving parts and the necessary vortex motion is performed by the liquid itself (Figure 7). They are configured so that when manure is pumped at an angle into the cyclone near the top, it swirls at a high speed. The strong swirling motion separates the solids by pushing them outward where they settle by gravity at the bottom of the cone. The liquid exits from the top of the cone through a fixed tube in the centre of the top. These separators require booster pumps at 30 psi or more.

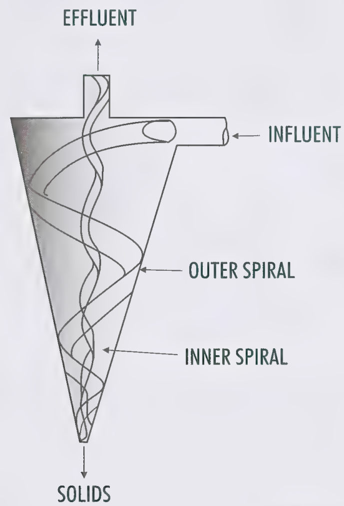


Figure 7. Hydrocyclone adapted from Shutt et al., 1975

Filtration/Pressing

Presses act as continuously fed de-watering devices that involve the application of mechanical pressure to provide additional separation of the manure slurry. They are used to remove additional water from the separated solid portion which is produced following screening or centrifugation. This physical separation process typically achieves a high level of de-watering and the pressed solid cake can be composted. The four main types of mechanical filtration devices are roller, belt, screw and filter presses.

Roller Press

This type of press has two concave screens and a series of brushes or rollers. The manure slurry is initially deposited onto the first screen and then moved across the two screens with brushes. The liquids are squeezed through the solids and the solids remain on the screen. The following two separators use these principles in their operation.

a) The **Brushed Screen with Press-Rolls**, also referred to as a Brushed Screen/Roller Press, separates solids from manure slurry using a screen in the first stage (Figure 8). The screen is kept clean by a rotating brush which moves the solids on to the next stage. Here, a roller presses more liquid out of the solids. The concentrated solids are then brushed out of the separator and transferred to storage.

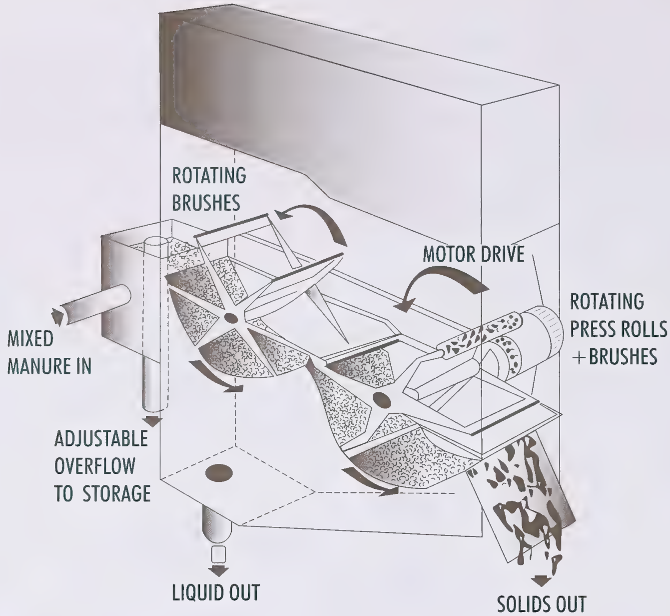


Figure 8. Brushed Screen with Press-Rolls adapted from Farrow Irrigation, 1978

b) The **Perforated Pressure Roller Separator** is a two-stage double roller compression separator (Figure 9). Liquid slurry is force-fed into the first set of perforated separator rollers. Separated liquid is removed at this point for storage. Separated solids from the first stage are conveyed to the second set of separator rollers where the fibre solids are removed by a mechanical conveyor to the storage area. The liquid fraction is drained off at this point and returned to the initial liquid slurry tank.

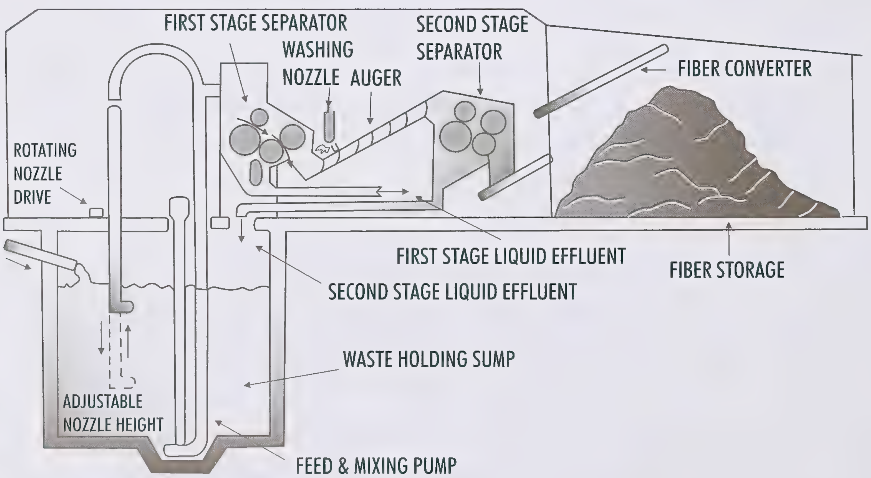
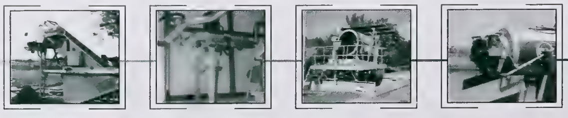


Figure 9. Perforated Pressure Roller adapted from Rorick et al., 1980



Belt Press

The belt press consists of a flat, woven, fabric belt that runs horizontally between rollers (Figure 10). The liquid is forced through the belt by the rollers and the solids are carried along the belt and dropped into a solids collection chamber.

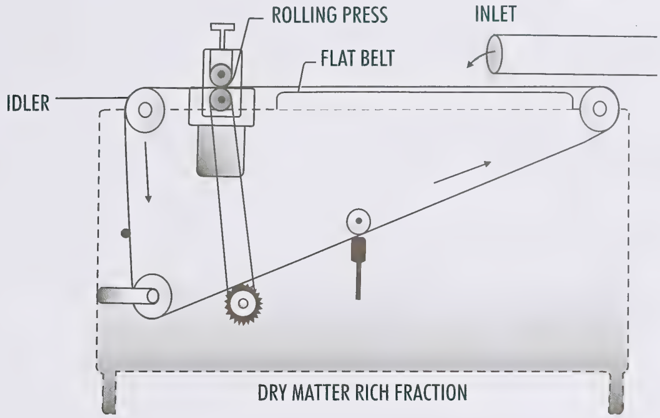


Figure 10. Belt Press adapted from Møller et al., 2000

Screw Press

The screw press (Figure 11) is composed of a screw-type conveyor in the centre of a cylindrical tube that forces the liquid through the screen. The screw moves the solids retained on the screen to the end of the tube where the solids are discharged.

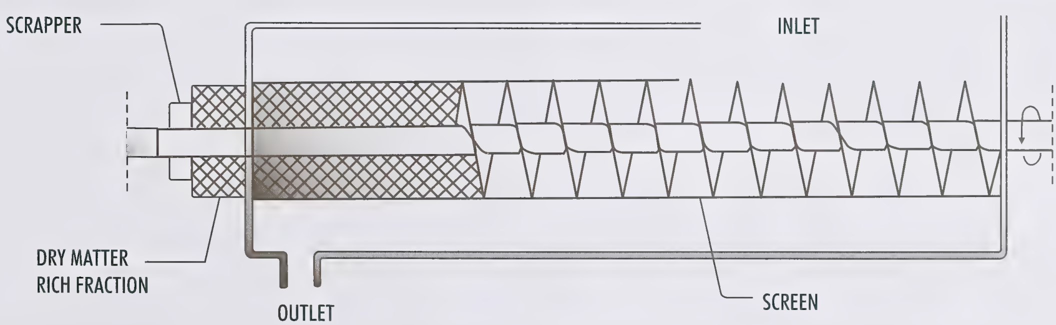
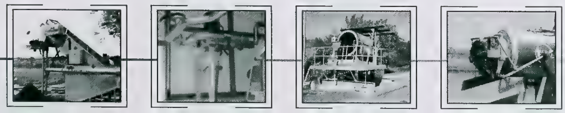


Figure 11. Screw Press adapted from Møller et al., 2000



Filter Press

This category of presses includes vacuum filters and chamber filter presses. The use of a filter cloth is incorporated into these designs for further solids removal.

a) A **Vacuum Filter** consists of a slow-revolving drum which is divided into a number of sections. It moves partly through the liquid to be treated. A filter cloth is fitted over the drum and one or more rollers. A vacuum is established in the sections moving through the liquid and the liquid is forced through the cloth. Solids are deposited on the cloth and removed by means of a scraper.

b) **Chamber Filter Press** separators may also be termed "pressure filters." The manure to be separated is introduced into the filtration chambers. These chambers are configured as plates which are forced against one another to dehydrate the manure. The number of chambers or plates may vary and they are equipped with a filtering cloth.

Chemical treatment

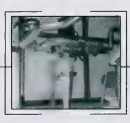
Chemical treatment involves the addition of chemicals to alter the physical state of dissolved and suspended solids and to facilitate their removal through a physical separation process. This form of treatment includes chemical precipitation, particle coagulation, and particle flocculation.

Chemical precipitation is the formation of an insoluble precipitate through the chemical reactions between the dissolved ions in wastewater such as phosphate and the metal ions, commonly calcium (Ca^{+2}), iron (Fe^{2}+ or Fe^{3+}), or aluminum (Al^{3+}). This process is most commonly used for the removal of dissolved P in wastewater.

Coagulation is a process of gathering solids that are suspended in a liquid into a mass to form particles that can settle. Flocculation is a process that converts coagulated particles into large, rapidly settling masses, also called flocs.

The most common chemicals used to coagulate and flocculate solids in animal manure and wastewater are organic polymers such as polyacrylamide (PAM), and metal salts such as ferric chloride ($FeCL_3$), alum ($Al_2(SO_4)3$) and lime (Ca(OH)2). Treatment with polymers prior to mechanical removal of gravity settling has the potential for enhancing solid-liquid separation and increasing the capture and removal of fine suspended solids.

Laboratory studies have found that $FeCL_3$ and $Al_2(SO_4)3$ are effective coagulants that help manure solids to gravity settle by sedimentation. A polymer used with $FeCL_3$ or $Al_2(SO_4)3$ produces dense flocs and helps remove solids by the process of screening.

Performance of Separators

Each kind of separator works best in certain types of livestock operations. One measure of the ability of a separator to work well in a certain operation is the separation efficiency which is the percentage of total solids removed from liquid manure. Each system is designed to separate a range of particle sizes. Its efficiency depends on the flow rate of the manure, the shape and size distribution of the particles, and their chemical nature. When you are considering solid-liquid separation systems for your operation, base your choice on the type and volume of liquid manure and wastewater that your operation generates. Some separation systems are ineffective when used alone in some types of operations. Sedimentation and mechanical separation systems have low separation efficiencies. Neither system effectively removes finer solids (less than 0.25 mm or 0.01 inch in diameter) which can create a number of odour-producing compounds when carbohydrates, proteins and fats decompose anaerobically (without free oxygen). These finer solids also contain nutrients such as N and P. Therefore, sedimentation or mechanical separation alone may not significantly reduce odours or nutrients from manure and wastewater.

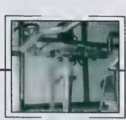
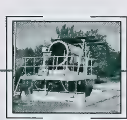
Sedimentation

When designing a sedimentation basin, the primary factors to consider are the manure and wastewater flow rate, the solids settling rate and the detention time (time between inflow and outflow of liquid manure). Studies show that sedimentation seems to be most effective for treating highly diluted manure and wastewater (flushed manure or feedlot runoff) consisting of less than 3 percent total solids. Generally, settling is reduced if the manure is more than 1 percent suspended solids. The separation efficiency for sedimentation basins (total solids removed) has been reported as high as 64 percent for a concrete swine feedlot and 39 to 75 percent for an earthen beef feedlot. In the latter case, much of the solids load consists of relatively large soil particles detached from the corral surface during rainfall.

Mechanical separators

An ideal mechanical solid-liquid separator is one that will remove a large percentage of solids from the liquid fraction and produce a solids fraction with a low moisture content (< 75 percent). Zhang and Westerman (1997) compiled available data on the performance of mechanical separators used to treat livestock waste. The data on swine waste separation units has been summarized and presented in Table 1.

Stationary screens typically produce a solids fraction with high moisture content and retain only a small fraction of the nutrients within the solids. However, this option is usually the least expensive (Fleming, 1986). Rotating screens, especially, tend to have very low separation efficiencies (MWPS, 1997). Screen characteristics will greatly affect their performance. Smaller screen openings will generally yield higher separation efficiency with respect to total solids (TS) but the solids fraction will have higher moisture content. Zhang and Westerman state that screen separators work most effectively when slurry TS concentrations are below 5 percent to avoid clogging. Screen separators would be of little use in treating swine manure as they


typically do not remove small particles (Ndegwa et al. 2000). Mechanical screen separators remove only a small fraction of total nitrogen (TN) and total phosphorus (TP) and produce solids fractions with moisture contents > 85 percent. Moller et al. (2000)

Table 1. Summary of available mechanical separator performance results (modified from Zhang and Westerman, 1997 and Westerman, 1997)

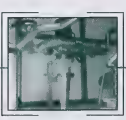
SEPARATOR TYPE	MOISTURE CONTENT OF SOLIDS (%)	SEPARATOR EFFICIENCY (%) (ON MASS BASIS)			
		TS	COD	TKN	TP
STATIONARY SCREEN	93	20	35	5	6
VIBRATING SCREEN	84	20	18	21	26
ROTATING SCREEN	86	10	7	8	6
CENTRIFUGE	85	35	25	15	62
BELT PRESS	83	50	40	33	20

Field tests have been conducted on the separation efficiencies of different types and brands of mechanical separators. The performance of those different mechanical separators has varied widely. Efficiencies ranged from 3 to 67 percent of total solids removed depending on the screen size (openings), the type of manure and the flow rates used. Studies show that screens perform much better with manures containing less than 5 percent solids. Higher flow rates and solids content tend to clog screen openings, causing more water to accumulate on the screen surfaces and more moisture remaining in the solids. Presses and centrifuges have higher separation efficiencies than screens and produce relatively drier solids.

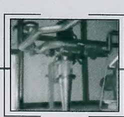
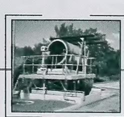
Chemical treatment

Laboratories have tested how well chemicals help separate solids in animal manure by coagulation and flocculation but there is no standard method for testing in the field. Some bench scale studies have shown that many more total solids are removed when sedimentation or mechanical separation is followed by chemical treatment of liquid manure. Researchers are working to establish the optimum dosing (i.e. continuous feed) for these chemicals.

The costs involved in separating solids from liquid manure, process-generated wastewater and open-lot runoff include the cost of the separating system, construction and/or installation, energy and labor to operate the system, and system maintenance and repairs.

Mechanical separators range from $10,000 to more than $50,000, not including the cost of pumps sumps and channels. Their throughput capacities (the amount of liquid manure and wastewater processed) vary from 100 to 600 gallons per minute. For the same capacity, screens cost less than centrifuges or presses. Some manufacturers provide options to install presses on a screen separator to remove more water from the separated solids. When selecting the separation method and equipment for a particular manure management system, consider the amount of manure and process-generated waste to be treated, the objective of solid-liquid separation and the planned use of the separated solids.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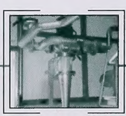

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